An Analysis of Multipath Routing in Mobile Ad Hoc Networks

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Abstract

Mobile Ad hoc networks (MANET) are communication networks that consist of wireless nodes, which placed together in an ad hoc manner. Nodes can enter or leave the network at any time, so that the network topology changes frequently. In this paper we are going to propose an algorithm for routing in mobile ad hoc networks. Routing task has some challenging problem in MANETs, based on having dynamic and unplanned nature. For facing with these challenges we propose an Adaptive Multipath Ant Routing algorithm (AMAR) by combining ideas from artificial intelligence (AI) and multipath routing in this algorithm for improving the network performance. In an extensive set of simulation experiments, we compare this algorithm with AntHocNet and AODV and OLSR which are three reference algorithms in this research area.

Keywords: MANET, multipath routing

1. Introduction

One of the most important developments in recent years in the field of telecommunication networks is the increased use of wireless communication. In this field, we can make a difference between infrastructure networks and infrastructure less networks [1]. In infrastructure networks, a fixed, wired backbone is available, and all communication is directed over this backbone. In infrastructure less networks, such a backbone does not exist, and wireless devices communicate directly with one another through point-to point connections. They are also referred to as ad hoc networks. Mobile Ad hoc Networks (MANETs) take place in infrastructure less networks. One of the biggest challenging problems in these networks is routing. Routing is the task of constructing and maintaining the paths that connect remote source and destination nodes, while maximizing network performance. This task is particularly hard in MANETs due to issues that result from the particular characteristics of these networks. The first important issue is the fact that MANETs are dynamic networks. The second issue is the unreliability of wireless communication. The third issue is caused by the limited capabilities of the MANET nodes. Finally, the last important issue is the network size. So due to these different challenges, it is important to design algorithms that are adaptive, robust and self-healing. Moreover, they should work in a localized way, due to the lack of central control or infrastructure in the network. Nature's self-organizing systems show precisely these desirable properties. Because of these same properties, they have recently become a source of inspiration for the design of routing algorithms for dynamic networks.

Routing protocols for ad hoc networks can be classified into different categories according to the following criteria:

- Pro-active, re-active or hybrid
- Centralized or distributed
- Dynamic or static

Pro-active protocol(s)	Re-active protocol(s)	Hybrid protocol(s)
OLSR OSPF TBRPF	AODV-BR AOMDV TORA MP-DSR ROAM SMR CHAMP MSR	ZRP

Table 1: Optical Routing Protocol classification

2. Multipath Routing in ad hoc networks

Mobile ad hoc networks (MANET) are characterized by a dynamic topology, limited channel bandwidth and limited power at the nodes. Because of these characteristics, paths connecting source nodes with destinations may be very unstable and go down at any time, making communication over ad hoc networks difficult. On the other hand, since all nodes in an ad hoc network can be connected dynamically in an arbitrary manner, it is usually possible to establish more than one path between a source and a destination. When this property of ad hoc networks is used in the routing process, we speak of multipath routing. Multiple paths can also provide load balancing and route failure protection by distributing traffic among a set of disjoint paths.

Paths can be disjoint in two ways: (a) link-disjoint and (b) node-disjoint. Node-disjoint paths do not have any nodes in common, except the source and destination, hence the do not have any links in common. Link-disjoint paths, in contrast, do not have any links in common. They may, however, have one or more common nodes.

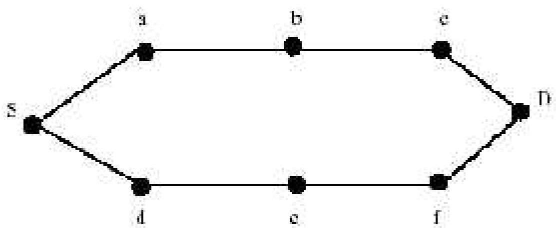

Fig 1a. Two node-disjoint paths from source *S* to destination *D*.

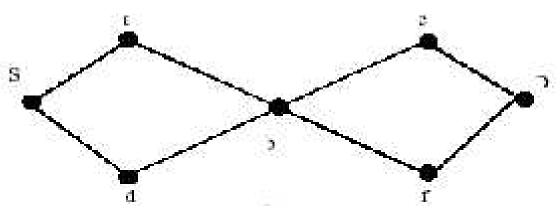

Fig 1b. Two link-disjoint paths from source S to destination D. Note that they are not node-disjoint, since they share node b.

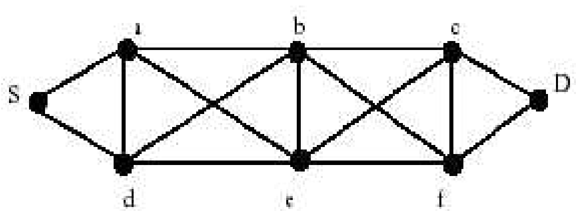

Fig 1c. The two node-disjoint paths from figure 1a, when they are in each other's radio coverage.

In order to use multiple paths simultaneously they need to be as independent as possible. So not only do they need to be disjoint, also route coupling must be taken into account, because routes can interfere with each other. Route coupling takes place when a path crosses the radio coverage area of another path. There is a protocol that uses this property of radio broadcast to create backup-routes [26], but in the case of multiple-path data transport route coupling is unwanted. Routes may be link- or even node-disjoint but still interfere with each other due to route coupling.

Consider the node-disjoint routes of figure 1a again. In the situation of figure 1c, when node a for example sends data to node b (both route 1), node d on the other route cannot transmit data to e on route 2, since the nodes (and thus routes) are in each others radio coverage area and interfere with each other. Since none of the routing protocols take the route coupling into account, we will ignore it in the sequel. Disjointness will be the only measure used for path independence.

2.1 Benefits of Multipath Routing:

As mentioned before, multiple paths can provide load balancing, fault-tolerance, and higher aggregate bandwidth. Load balancing can be achieved by spreading the traffic along multiple routes. This can alleviate congestion and bottlenecks. From a fault tolerance perspective, multipath routing can provide route resilience. To demonstrate this, consider Figure 4, where node S has established three paths to node D. If node S sends the same packet along all three paths, as long as at least one of the paths does not fail, node D will receive the packet. While routing redundant packets is not the only way to utilize multiple paths, it demonstrates how multipath routing can provide fault tolerance in the presence of route failures.

Since bandwidth may be limited in a wireless network, routing along a single path may not provide enough bandwidth for a connection. However, if multiple paths are used simultaneously to route data, the aggregate bandwidth of the paths may satisfy the bandwidth requirement of the application. Also, since there is more bandwidth available, a smaller end-to-end delay may be achieved. Due to issues at the link layer, using multiple paths in ad hoc networks to achieve higher bandwidth may not be as straightforward as in wired networks. Because nodes in the network communicate through the wireless medium, radio interference must be taken into account. Transmissions from a node along one path may interfere with transmissions from a node along another path, thereby limiting the achievable throughput. However, results show that using multipath routing in ad hoc networks of high density results in better throughput than using unipath routing.

2.2 Basic Principals in Designing Multipath Routing Protocols:

Although the multipath routing approach has been employed for different purposes, the achieved performance gain is highly affected by the ability of the proposed protocol to construct an adequate number of high-quality paths. Each multipath routing protocol includes several components to construct multiple paths and distribute network traffic over the discovered paths. In the following, we describe these components in detail.

Path Discovery: Since data transmission in wireless sensor networks is commonly performed through multi-hop data forwarding techniques, the main task of the route discovery process is to determine a set of intermediate nodes that should be selected to construct several paths from the source nodes towards the sink node. Different parameters are used in the existing multipath routing protocols to make routing decisions. Among these parameters, the amount of path disjointedness is the main criterion which is utilized by all the existing multipath routing protocols to discover several paths from each sensor node towards the sink node. As depicted in Figure 1, discovered paths can be generally categorized as node-disjoint, link-disjoint, or partially disjoint paths. For node-disjoint paths, there is no common node or link among the discovered paths. Therefore, any node or link failure in a set of node-disjoint paths only affects the path, which contains the failed node or link. Since this kind of path disjointedness provides higher aggregated network resources, node-disjoint paths are preferred over link-disjoint and partially disjoint paths. Still due to the random deployment of the sensor nodes, it is difficult to discover a large set of node-disjoint paths between sensor nodes and sink node. In contrast, link-disjoint paths may contain several common nodes while there is no shared link between the paths. Accordingly, any node failure in a set of link-disjoint paths may deactivate several paths that share the failed node. Finally, partially disjoint paths can include multiple paths, which may share several links or nodes between different paths. In comparison with the aforementioned types of path disjointedness, any link or node failure in a set of partially disjoint paths may affect several paths. However, constructing multiple partially disjoint paths can be easily performed. Regarding to the advantages and disadvantages of different types of path disjointedness, network density and performance requirements of underlying application play an important role to make the best decision between using node-disjoint, link-disjoint or partially disjoint paths.

The amount of path disjointedness is the basic criteria that should be considered for discovering a set of paths, but due to the time-varying properties of radio communications and resource limitations of the sensor nodes, only considering this criterion may not result in the construction of high-capacity paths. In some situations, merely assuming the amount of path-disjointedness for route discovery may lead to the construction of several low-quality paths. To address this problem, in addition to the amount of path disjointedness, different routing algorithms utilize various routing cost functions to make the best routing decision based on the application related performance demands. The main purpose of a routing cost function is to capture various properties of wireless links and sensor nodes to calculate cost of data transmission over different paths. To this aim, the employed routing cost functions in the existing multipath routing protocols are composed from several components to measure the capability of different nodes or links to provide performance demands of various applications (e.g., maximizing path throughput, minimizing end-to-end delay, improving network lifetime, and even traffic distribution). Path length, packet loss rate, delay and residual battery level of the sensor nodes are among the basic components of the routing cost functions utilized by the existing multipath routing protocols.

This is to preserve the freshness of the established interest tables at the intermediate nodes, while it also maintains the discovered paths. When the active path fails to forward data packets, another available path can be used to provide fault-tolerant routing. Accordingly, whenever the data reception rate from the active path is reduced, the sink node reinforces the second available best path.

The suggested taxonomy classifies the existing multipath routing protocols into three main categories (i.e., alternative path routing, multipath routing for reliable data transmission, and multipath routing for efficient resource utilization), based on the employed path selection and traffic distribution mechanisms.

Table 2. Summary of the multipath routing protocols with alternative path routing

Features / Protocols	Path Disjointedness	Route Maintenance	Traffic Distribution	Number of Paths	Path Chooser	Improved Performance Parameters
Directed Diffusion	Partially disjoint	New route discovery when all the active paths have failed	Not applicable	Not limited	Sink node	▪ Data transmission delay caused by path failure ▪ Packet loss rate caused by path failure
Braided Multipath Routing	Partially disjoint	New route discovery when all the active paths have failed	Not applicable	Not limited	Sink node	▪ Data transmission delay caused by path failure ▪ Packet loss rate caused by path failure ▪ Route discovery and path maintenance overhead
Reliable and Energy-Aware Routing	Node-disjoint	New route discovery when the primary path has failed	Not applicable	Two paths	▪ Source node ▪ intermediate nodes	▪ Packet loss rate caused by path failure ▪ Network lifetime

Directed Diffusion is a query-based routing protocol that uses the concept of multipath routing to provide path failure protection. Figure 2 shows the main operations of this protocol. According to Figure 2(a), routing operation is initialized by the sink node through flooding interest messages throughout the network. These interest messages contain some information regarding to the task that should be performed by the sensor nodes. During this stage, all the intermediate nodes cache the *interest* messages received from their neighbors for later use. Moreover, upon reception of an *interest* message, the receiver node creates a gradient towards the node from which this message has been received. As it can be seen from Figure 2(b), in this stage several paths can be discovered between each pair of source-sink nodes. After that, whenever a source node detects an event matched with the existing information in its interest table, it forwards its data packets towards the sink node through all the constructed gradients. The sink node receives its requested data through several paths with a low-data rate. Based on the packet reception performance over each path, the sink node can select the best path, *i.e.*, the path with minimum latency, for data transmission. For this, the sink node reinforces the selected path by sending low-rate *reinforcement* messages towards the source node. Then, the source node merely transmits its data towards the sink node through the selected path. This process is demonstrated in Figure 2(c). Furthermore, sink node continues to send low-rate *interest* messages over the remaining paths. This is to preserve the freshness of the established interest tables at the intermediate nodes, while it also maintains the discovered paths. When the active path fails to forward data packets, another available path can be used to provide fault-tolerant routing. Accordingly, whenever the data reception rate from the active path is reduced, the sink node reinforces the second available best path.

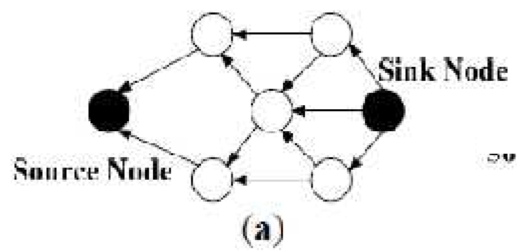

Fig 2(a) Interest propagation;

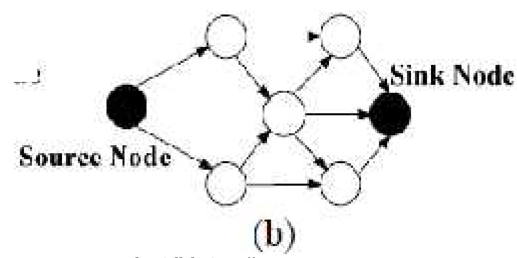

Fig 2(b) Gradient setup;

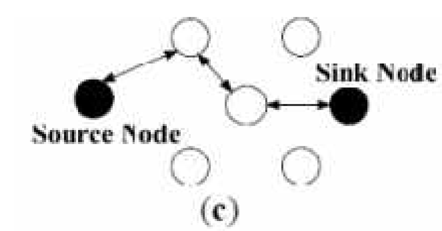

Fig 2(c) Path reinforcement and data transmission

Braided Multipath Routing Protocol

This protocol is a seminal multipath routing protocol proposed to provide fault-tolerant routing in wireless sensor networks. This protocol uses a similar approach as Directed Diffusion to construct several partially disjoint paths. A general form of the established paths is presented in Figure 3.

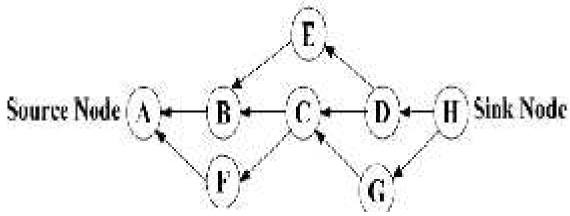

Fig 3. Braided multiple paths.

This protocol utilizes two types of path reinforcement messages to construct partially disjoint paths. Path construction is initiated through the sending of a primary path reinforcement message by the sink node to its best neighboring node towards the source node. For example, in Figure 3, the sink node sends the primary path reinforcement message to node D. When an intermediate node receives a primary path reinforcement message, it forwards this message to its best next-hop neighboring node towards the source node. This process is repeated until the primary path reinforcement message reaches the source node.

Reliable and Energy-Aware Multipath Routing

This Protocol is designed to mitigate the energy efficiency requirement of wireless sensor networks, while provides reliable data transmission through maintaining a backup path from each source node towards the sink node. Similar to the above presented protocols, the routing operation in this protocol is also initialized by the sink node. In this way, whenever the sink node receives an interest message from a source node and there is no active path towards the source node, it initiates a service-path discovery process through flooding a service-path request message. Upon reception of the service-path request message at the corresponding source node, the receiver node transmits a service-path reservation message towards the sink node (through the reverse path) to confirm the discovered path. While the service-path reservation message moves from the source node towards the sink node, whenever a node along the reverse path receives this message, it reserves a part of its residual battery level for data transmission over this path. The service-path construction process finishes by receiving the service-path reservation message at the sink node. Afterwards, the source node can transmit its data packets towards the sink node through the constructed path. After constructing the service-path, sink node initiates another path discovery process to establish a backup path towards the same source node by flooding a backup path discovery message. During this process, the intermediate nodes, which are not a member of the discovered service-path, broadcast the received backup path discovery message to their neighbors. Therefore, a node-disjoint path is created to provide fault tolerance in the case of service-path failure.

Although this protocol provides energy-efficient and reliable data transmission, however it suffers from the main disadvantage of the alternative path routing strategy: the end-to-end capacity is limited to the capacity of a single path. More importantly, this protocol neglects the effects of wireless interference and link unreliability on the required energy for successful data transmission.

Conclusions and Future Directions

This paper provides a comprehensive analysis of the most recently proposed multipath routing protocols for wireless sensor networks. Nowadays, multipath routing techniques are considered an efficient approach to improve network capacity and resource utilization under heavy traffic conditions. With respect to the recent advances in the development of multipath routing protocols for wireless sensor networks, there is a need to investigate the significance as well as the detailed operation and classification of the proposed approaches. To fill this gap, in this paper we have attempted to identify the challenges pertaining to the design of multipath routing protocols for wireless sensor networks. In addition, we have highlighted the main advantages of using multipath routing approach to satisfy the performance requirements of different applications. This paper also introduces a new taxonomy on the multipath routing protocols designed for wireless sensor networks. The provided classification is performed based on the employed path utilization methods that can be used by multipath routing protocols to achieve various performance benefits.

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